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# Stop the Noise! Enhancing Meaningfulness in Participatory Sensing with Community Level Indicators

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## ABSTRACT
In this paper we examine ways to make data more meaningful and useful for citizens in participatory sensing. Participatory sensing has evolved as a digitally enabled grassroots approach to data collection for citizens with shared concerns. However, citizens often struggle to understand data in relation to their daily lives, and use them effectively. This paper presents a qualitative study on the development of a novel approach to Community Level Indicators (CLIs) during two participatory sensing projects focused on noise pollution. It investigates how CLIs can provide an infrastructure to address challenges in participatory sensing, specifically, making data meaningful and useful for non-experts. Furthermore, we consider how this approach moves towards an ambition of achieving change and impact through participatory sensing and discuss the challenges in this way of working and provide recommendations for future use of CLIs.

### Author Keywords
Community Level Indicators; Noise pollution; Participatory Sensing; Research Methods; Co-Design

### ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

## INTRODUCTION
Half of the world's population now lives closely together in urban cities, with rises expected [36]. This urban living comes with many environmental challenges and concerns e.g. water, noise and air pollution. Local governments may not have the capacity to deliver solutions or to address citizens' pressing needs [27]. In response, HCI is increasingly developing civic tech to help address the needs of communities. One way this is happening, is through the development of participatory sensing tools that allow people to collect and share data on matters of concern, for example, environmental pollution.

There is the opportunity to enable community-led action for local environmental change through participatory sensing. These types of citizen measurement initiatives exist in broader fields, such as citizen science [10]. Participatory sensing, as discussed here, utilises technology in community-led activities, and is intended to empower citizens through their participation [7]. However, there are still many obstacles to overcome in this field. Three of them considered in this paper are:

1) generating and communicating information and understanding [32, 31],
2) analysing and finding relevance in data [21, 8, 3],
3) achieving or monitoring change and impact [12, 11, 25].

Based on these challenges, we posit that there is a need for methods and tools to assist non-experts in making data meaningful and expanding their understanding of the information they obtain. This positioning has resonance in the wider field of HCI [35, 20]. Previous studies show that people struggle to make sense of this sensor data or integrate it into their everyday life in meaningful ways [7]. Moreover, there is a lack of methods to track and assess impacts, in particular from the perspective of the beneficiary community.

We have sought to address these gaps by proposing Community Level Indicators (CLIs) as a novel infrastructure for participatory sensing. We position the CLIs approach as a way to collaboratively collect indicators - information captured by the community that contextualises and complements sensor data. By novel



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infrastructure we mean a process of developing socially engaging technology that can be used and appropriated beyond the capacity of the original design by those not necessarily included in the process [29].

In this paper, we discuss the development of the CLIs approach through a research through design journey, and consider how it can assist in expanding participatory sensing beyond a technological focus and towards a more socially engaged and action driven process. We demonstrate how this approach may be used by citizens to monitor change and impact, understand the data they collect and use it to create long-term change. We contribute recommendations for the application of CLIs in participatory sensing where change-making is an objective.

## BACKGROUND

The proliferation of participatory sensing has been due, in part, to the increased accessibility of small, affordable sensing devices such as the Air Quality Egg [2] or the AirBeam [1]. Such technology is designed to help citizens collect data on their environment, raise awareness of environmental issues, support behaviour change, or even lobby policymakers for change [1].

Participatory sensing has arisen as a bottom-up approach to data collection led by citizens and driven by collective issue identification and action [11, 7]. However, researchers in this area [32] call for further investigation into maintaining sustainable communities of participatory sensing as well as taking advantage of the dynamic social relationships and collective capabilities of participants.

One way to encourage sustainability is through community empowerment, which includes opportunities for citizen participation in decision-making and fair treatment of different perspectives [39]. Such participation in community organisations has been related to increased competencies, confidence, sense of citizen duty, and lower feelings of helplessness, thus supporting the idea that this kind of participation increases empowerment [22]. Citizens are empowered when they understand evaluation and connect it in a way that it has relevance to their lives [21].

A review of four participatory sensing studies [3] examined the factors that drive participation in these types of collective activities. This review found that the primary motivation amongst participants was the desire for personally relevant information, especially when health was a matter of concern [3]. Primarily, they were interested in the data being explained or being contextualised without a need for technical knowledge [3].

This paper examines an additional approach in participatory sensing through the use of Community Level Indicators (CLIs). We position this into the field of HCI and demonstrate how this concept has relevance to participatory sensing in the following section.

### Community Level Indicators

The concept of CLIs or indicators is derived from a variety of fields including health, ecology, design, sociology, social science, resilience studies and media studies [24, 17]. While some definitions refer to group or community measures rather than individual [37, 12], others focus on measuring particular trends or outcomes [9, 23, 28]. Although nuanced in their differences, existing definitions share a common focus in that they understand indicators as something (or many things) which can be monitored and can determine whether or not change occurs as a result of an intervention - be it a campaign, policy or other action [38]. For example, during a noise pollution campaign a community could collect CLIs that reflect their perception of where the noise comes from and the impact it has on their lives. In this case, some possible indicators could be:

- number of cars driving on certain streets
- number of warning flags hanging in balconies [Figure 1]
- volume of ear plugs purchased in certain areas
- the number of people being treated for stress related health problems in noisier areas compared to quieter ones


**Figure 1. "Stop the noise, respect!!!" Citizens demonstrate their issue of concern using a very public display of warning flags outside a residential apartment in Barcelona.**

Developing and monitoring CLIs is a new community centred approach to evaluation methods. The extension of CLIs to participatory sensing responds to a need to document the long-term progress and impact of grassroots data collection [13]. To address current gaps in participatory sensing, CLIs are positioned as complementary information to sensor data and can be used to better understand the sources and causes of environmental issues [38, 14]. Individually they can be inadequate, but in combination with sensor data CLIs can reveal trends to identify areas for action [26]. They differ from sensor data in that the indicators are chosen as important to measure by the community, they are not solely numerical measurements and they are designed to sit

alongside sensor data to improve understanding of the situation in a more holistic way.

Some of this information could be available through existing research, like national health records. Citizens, through monitoring their local environment and keeping a record of their daily activities, could collect other information. An example of this could be keeping notes in a diary. It is important for Community Level Indicators to be designed and chosen by the community. This is a process that can begin early in the study and is illustrated below.

There is a need to measure and assess the impact of citizen sensing interventions that occur in the wild and aim to address community needs. In many cases, community technology efforts are reported in the literature with a focus on the evaluation of the technology itself rather than whether it achieved the results that motivated its design from the perspective of the participating community. As a result, researchers working in participatory design are increasingly interested in devising impact assessment methods that are not top-down or exclude target communities from direction setting [37]. CLIs could be evidence of goal achievement (e.g. reducing noise pollution in a neighbourhood), learning new skills, sustaining number of participants, or scaling up the intervention to reach other groups and communities [15, 38].

CLIs seek to make the invisible, visible. By this we mean that the abstract outcomes of socially oriented campaigns (i.e. awareness, change or community empowerment) can be difficult to capture on their own. CLIs are objective and measurable proxies, which create more reliable scientific or policy-ready evidence to justify action or change. However, having participants understand and devise CLIs is a not an easy feat. Even more so when many are new to the fields of participatory sensing and grappling with the technology and concepts around gathering information through mobile devices. Therefore, this study explores the development of tools and process to introduce and facilitate the CLIs approach. Through a review of two participatory sensing projects, we discuss how the CLI approach was delivered, reflected on and iterated. We also discuss learnings from the development of this approach and recommendations for further research in the area.

## RESEARCH CONTEXT: MAKING SENSE

The use of CLIs were applied in two participatory sensing pilots, alongside the Smart Citizen Kit (SCK) [Figure 2] [34], as part of the H2020 project, Making Sense. The SCK is a sensor and online platform, developed from open source software and hardware and designed to support sustainable and scalable environmental participatory sensing initiatives. Previous research, however, identified deterrents for wider uptake of SCKs, one of which was a limited understanding of the relevance the data had in the users' daily lives [5, 6]. As such, a key objective for Making Sense was to explore new approaches in enhancing data meaningfulness in participatory sensing.

Making Sense was conducted across three European cities: Amsterdam, Barcelona and Prishtina, and explored a range of environmental challenges. This paper focuses on the activity in Barcelona, as this is where the CLIs were delivered as part of the research strategy and were conceptualised, developed and iterated during a 24-month period. The first study was titled 'Community Champions' and aimed at testing technologies and methodologies in participatory sensing. It had a focus on community building as well as developing approaches for shared understanding and making data meaningful. As a result of the pilot, the participants formed into a cohort of 25 Community Champions who had a level of understanding and skills which they could pass on to future participants. The second pilot, called 'Gracia Sounds', included several participants who were Community Champions from the first pilot. The rest of the participants were residents from a specific geographical area in Barcelona, where the issue of noise pollution was a real concern for local residents and the government.


**Figure 2. The Smart Citizen Kit (SCK); sensor and online platform.**

## RESEARCH APPROACH

This study followed a research through design approach, where the problem and its complexity is understood and tools are developed through ideation, iteration and critiquing solutions. The end goal is not to achieve a definitive solution but rather to explore the problem and articulate preferred states of being through tangible artifacts such as prototypes, models and process documentation [40]. The objective of the CLI approach was to enhance knowledge and understanding of participatory sensing, data meaningfulness, and to devise public facing actions for impact and change. The project team (those delivering the participatory sensing projects) brought CLIs into the pilots to consider how this new concept could be integrated into existing participatory sensing processes.

The concept and first iteration of the tools were initially developed through a report written for the European Commission [38]. The specific CLI tool was informed by Lucy Kimbell's [28] *Creating a futures outcomes framework*, as this method enables diverse stakeholders to

identify their shared goals and monitor the indicators that assess whether these goals have been achieved. The tools and engagement process in the wider participatory sensing project were delivered and tested as part of a series of face-to-face participant workshops. Research on this process of development, with specific focus on CLIs, was conducted through a mixed-methods approach. Methods included: collecting ethnographic observations in field journals, interviews with participants, documentary photography and thematic analysis. Summaries of the use of CLIs in the two studies are presented below. Following these reviews, the discussion examines the impact CLIs had in the pilots and how they address our identified challenges for participatory sensing.

### Community Champions

The Community Champions pilot ran over three months and was organised through weekly meetings with the participants and project team. Several workshops were delivered during the pilot that were intended to upskill the participant in various topics such as understanding data. These workshops were also conducted to co-create (participants, project team and experts) the design of various aspects of the pilot, such as the research questions, the sensor technologies and the data collection strategies.

The second workshop of the Community Champions pilot aimed to enhance participant knowledge and support discussions on the complex issue of noise. The participants (n=18) and project team (n=8) also discussed foundational ideas of participatory sensing and data collection. Participants included citizens of Barcelona, a mix of gender and adults ranging in ages from 18-70. In this workshop the participants agreed on the collective goals for the pilot and proposed and developed CLIs that could be collected in relation to monitoring the achievement of those goals.

The workshop included several methods to help facilitate a discussion on CLIs. The first was a Noise Timeline tool [Figure 3], where participants noted and marked different noises that they heard and noises that they made on a 24 hour timeline. This was intended to have participants think about noise as both something that they experience but also something that they create. Green and red sticker dots were then applied onto the timeline to distinguish between noises that were considered pleasing and those that were considered a nuisance. This sparked debate around noise associations, as some can find one noise soothing while others find it disturbing.

The second activity was one of collaborative goal setting, where concerns and expectations of the pilot were shared and concrete objectives were discussed. The two main goals chosen by the participants were to ‘reduce traffic noise’ and to ‘relate noise to stress’. The first two activities were designed to enable participants to think about the kinds of data they would find interesting and the measures they would like to collect. Following this, the participants used the collective goals to complete a bespoke CLI tool (see [Figure 6] for final version of CLI tool). This tool is composed of a large sheet that has, from left to right, a column for goals, a second column for the types of indicators that could be measured to track progress towards goals and a third column that includes how, who, when and how often these indicators should be collected. There was a vote for most popular indicator to be collected, which was ‘measure noise versus stress’ with a mobile app, by the participants over a month at daily intervals.

**Figure 3. Noise Timeline. Participants complete an activity unpacking the issue of noise using icons on a 24 hour timeline.**

### Gracia Sounds

The Plaça del Sol in the area of Gracia, Barcelona has a long-standing history of its residents suffering from exposure to noise from people loitering, drinking and creating noise in their neighbourhood. Working with the project team and the participants from the Community Champions pilot, the local residents aimed at gathering evidence on this ongoing problem and identifying pathways for actionable change. Equipping residents with the technology and through a programme of activities to support them in making data more meaningful, the residents were able to speak out on their problems with noise pollution and get the recognition from media and government that they needed to take steps towards resolution.

This pilot ran officially for five months, though activities occurred beyond the formal project timeline. Similar to the previous pilot, Gracia Sounds was organised around weekly meetings with the participants and project team. In this pilot, the CLIs workshop was introduced at a slightly later stage, after the participants had taken part in initial workshops focused on understanding some of the underpinning principles of participatory sensing and sensor technology. Prior to the CLI workshop, participants worked on a noise timeline activity and a sensor strategy. They identified three ways they wished to deploy the sensors: inside and outside their apartments, around the Plaça del Sol and on different floors of the apartment buildings. The idea to spread out the activities in the second pilot, was due to the reflections from the participants in Community

Champions pilot, and the observations from the project team.


**Figure 4. Participant contributions, from left 1) A sensing notes journal for annotating information, 2) Data visualization concepts, 3) prototype for a living wall noise reduction in the Plaça del Sol at the final public event of the Gracia Sounds pilot.**

The CLIs workshop included local residents (n=12), participants from the first pilot (n=7) and the project team (n=5). Residents were mixed gender and with a diverse range of ages, between 18-75. The first activity was a mapping exercise where residents marked where they lived and where they could deploy sensors. Residents and Community Champions then formed three groups, one for each of the above sensor deployment strategies. The strategy for the sensor deployment was considered the primary tool in collecting data on noise levels. Using a modified version of the CLI tool described above that included an additional column on strategy for collecting indicators, the groups came up with two supplementary indicators that could be paired with the sensor strategies.

This activity had the groups think about how to capture complementary information to the sensors. One group considered how the materials and physical structure of the apartment buildings affected noise. Another group decided that the residents should track their activities while at home, so that the data from the internal sensors could be annotated with noise that was being made by the residents themselves. The third group sought to track the people in the plaza by following pathways of movement in relationship to the areas of sunshine throughout the day. The aim was to compare this information to the sensor data and analyse the distance between the two. This idea stemmed from an observation where residents noticed how people moved throughout the plaza to chase the sunlight, and they were curious to discover if noise levels would increase according to the distance from the source.

## IMPACT OF THE CLI APPROACH

For the Community Champions pilot, the CLI approach had an impact in regards to their awareness of the problem. In subsequent discussions, participants would refer back to their observations from this workshop, and to the CLIs. Specifically, in regards to physiological responses to noise. For example, one participant found that their sleep deprivation was due to a nightly trash collection truck that would wake them up. During the Gracia Sounds pilot, many of the ideas from the CLI workshop re-emerged in ensuing discussions and residents continued to express interest in gathering evidence for their case for change.

Specifically in the case of the Community Champions pilot, a few participants found the leap between goal setting and the creation of CLIs a difficult one. Others were able to easily identify CLIs and methods for collection, even using other digital devices (i.e. a heart monitor to track stress), the data of which could be paired to the noise recordings. Overall it was observed that CLIs were introduced too early in the pilot process, since the workshop occurred very early in the pilot, in the second group meetup, when participants were only just being introduced to the aims of the project. Due to this, the goals of the participants shifted in following meetings, and the collection of CLIs fell outside their immediate objectives. Furthermore, it was also observed that the bespoke tool designed to facilitate the identification of indicators was deemed too complex for most participants to engage with at this early stage. These reflections were taken into consideration for the subsequent iteration and use of CLIs in the following pilot, Gracia Sounds.

Within the Gracia Sounds pilot, the CLI activity was repositioned and became a turning point in the residents' understanding of the complicated issue of noise. The group was driven by this chronic longstanding problem in their community; however, previous debates in public settings had not interrogated the issue. Given the opportunity to form smaller groups and consider CLIs, the groups discussed noise in a less abstract or accusatory way. Instead, they were able to create strategies to gather information, which would reveal insights about the data, and how it mirrored events in their lives. This was crucial, as it helped the residents move from a culture of blame to discussing the possibilities of collective participation. Through collective monitoring of CLIs, they discovered that they could take action into their own hands. During the pilot evaluation several residents reflected and commented that it made them feel "useful" and "empowered". As one remarked:

> We have the information, we have the data. We knew in the past that these noises were not normal, that it was high. We knew that we had to stand up because it's not a normal level but we have the evidence and we have the data that states the decibels we have here, so we should do something. (Interview Participant, Plaça del Sol Resident)

Some residents participating in the Gracia Sounds pilot filled out sensing journals to record annotated information about the data. For example, activities happening in Plaça del Sol which would have caused the sensor to capture high decibel readings, like a busker singing in the square. One participant, who had been involved since the Community Champions pilot, had been collecting the data and complementary information in their sensing journal. In addition, they discovered different types of materials that could absorb sound and found that certain types of moss had noise reducing abilities. Equipped with this information, they attended the final event of the pilot to propose a modular structure of moss panels that could be installed in Plaça del Sol to decrease the noise [Figure 4].

Some residents of Plaça del Sol collected information in other ways, for example, one resident took regular photographs of the people in the plaza during peak times using their mobile phone [Figure 5].

**Figure 5. A participant demonstrates how they have captured images evidencing a cause of noise pollution.**

They would take photographs several times a week when prompted by loud noises coming from the square. They would share these photographs with the community through the group conversation mobile application, "Whatsapp", where residents uploaded information that they collectively measured. This also formed an account of the number of people sitting in the square at specific times during the various nights of the week. This documentation was used to communicate the issue to policymakers in partnership with the datasets of noise levels gathered by the Smart Citizen Kits. Reaction from those who would receive the photographs is described as shock:

> They are surprised because they don't realise that this is happening. They know it because I have showed these photos one year ago when we had the first meeting. At first, they were very surprised but come on, we have this everyday! (Interview Participant, Plaça del Sol Resident)

This complementary information was easily understood and was used to annotate sensor data and as corroborating evidence of the issue over a long period of time. It allowed the residents to monitor the causes of noise, and to build a portfolio of complementary information which they used to argue their case for change to government. Since then, the government has changed the times in which they clean Plaça del Sol [4]. Moving the cleaning time from the middle of the night to a set time in the late evening still allows people to use the plaza as a social space during the day. However, the new cleaning times encourages loiterers to move on. As a result, the residents have reported that their homes are much quieter and their families are able to sleep better.

## LEARNINGS

The conditions in which the pilots were delivered differed from each other. The insights gleaned from the earlier Community Champions pilot were used to iterate the approaches and tools used within the follow on Gracia Sounds pilot. In the latter, there was a stronger focus of applying participatory sensing to a real-world challenge and with those directly affected by noise. In each pilot, introducing CLIs early helped to assist participants in discussing and question their assumptions around the complicated matter of noise. It aimed to support participants to collectively consider which indicators could help them track the progress of their actions or the impact of their campaigning. In Gracia Sounds, however, the approach was found to be more accessible and timely, in addition it helped to build consensus amongst the group.

Furthermore, for this study it was a way to test new methods for data sensemaking in HCI approaches to environmental awareness. The researchers reflected on the way the participants engaged with the CLIs, and how or if, this concept supported a building of awareness of the issue, and a process to development knowledge and understanding of collectively gathered information.

These insights demonstrate the outcomes from an initial exploration into the use of CLIs in participatory sensing. To build on this, the following section returns to the higher level challenge areas in participatory sensing, as outlined at the start of this paper, and discusses how the CLIs approach may tend to these challenges.

### Generating and communicating information and understanding

CLIs make data meaningful by providing complementary information to the sensor data, which helps to inform a wider understanding of environmental issues.

Fundamentally, CLIs provide an opportunity for the participants to frame the creation of data from the outset in ways that are meaningful to them. This enables an approach for making the data meaningful and useful that might otherwise be less available to them as non-experts. Through these studies we found that the concept of CLIs assisted participants to think more deeply about the issue of noise pollution. Complementing sensor data with other types of information revealed the causes and effects of noise pollution. It also challenged the assumptions of participants in relation to noise, and prompted them to think more deeply about the complexity of the issue.

However, one important challenge noted was that of communicating the value of this way of working to participants. For instance, in the case of Gracia Sounds, the residents found the workshop on CLIs beneficial to understanding the complex issue of noise and to discussing ways to gather information to make sense of the sensor data. There were a few participants who did not collect CLIs as initially planned but collected information in a different way. They did not make the connection between what they were gathering and the concept of indicators. Those actions and the activity of CLIs were viewed as two separate entities. To encourage the use of CLIs in this way of working, specifically in regards to communicating the problem, demonstrating their value is crucial. Stories of the resident who complemented the sensor data with photographs taken with her phone, and was subsequently able to show government officials the problem alongside sensor data, can encourage others to work in a similar way.

### Analysing and finding relevance in data

CLIs support data meaningfulness through demonstrating how to analyse the data and find the relevance of that information in real world challenges. They provide a platform or approach to enable greater awareness of data through a better understanding of the relevance and context of sensor data. This is further supported by evidence of an ongoing exploration of the data by the participants, and provides a way for interpretation in a more accessible way to the non-expert. This could be seen in the case of the Community Champions, who sought to explore other materials which could cause noise reduction. Through an analysis of material, they discovered that an installation of moss could assist in decreasing the severity of noise.

However, in the studies discussed above, it was still the case that data scientists or sensor experts had the primary role of analysing the sensor data and devising research based solutions or approaches for noise reduction. Those who had expertise in data interpretation did the majority of the analysis and presented it to the Community Champions and residents of Plaça del Sol. Once the data had been analysed, the participants were shown ways to make sense of the data by engaging in activities that supported them in understanding the relevance of the information. In Gracia Sounds, they compared the sensor data to the legal limits of noise as outlined by the government, and also to noise decibels recorded on one of the busiest streets of Barcelona.

However, there is scope here to use the CLIs with the analysed data to reveal further insights. For instance, when looking at data visualisation one could map spikes in noise readings with annotations from sensing journals to discover what were the causes of high readings. A more systematic approach to recording CLIs could substantiate information with metadata, e.g. time and place, which could provide more clear and comparable information to the sensor readings.

### Achieving and monitoring change and impact

CLIs in participatory sensing build on research from other fields, which suggest that they are key in devising pathways for achieving change and monitoring the progress towards change. This research has also found that there is a need for this type of information in participatory sensing. To advance the field of participatory sensing, an objective must be to move from sensing and awareness to action and impact, collectively. Combining complementary information with sensing data can help citizens evidence a need for action, and find their own pathways to address matters of concern. As was the case with the outcome of Gracia Sounds, where the government has changed the plaza cleaning schedule to ensure loiterers leave the area at an appropriate time and residents are given peace and quiet through the night.

It is not strictly the information captured which is valuable, further value stems from the bottom-up nature of creation. The identification and collection of CLIs is a collaborative process and challenges the notion that information must be received through a top-down model or delivered by established institutions. It encourages citizens to collect information to build strong arguments for change, and gives them a platform to discuss issues with policy makers.

## PRACTICAL RECOMMENDATIONS

CLIs could be embedded in a participatory sensing platform or utilised as a complementary method within a larger project as has been outlined above. There are several ways CLIs could be embedded into a platform, one way is through a decision making tool such as Loomio [30]. Citizens would be able to discuss, vote on and choose indicators they wanted to track throughout sensing. Another option would be to allow for contextual tagging of sensor data as indicators that the citizens have chosen and understood to be meaningful for them. Regardless of how they are implemented, we present below several practical recommendations for using CLIs in participatory sensing through lessons learned from our own work.

### Timing

Introduce CLIs at the start, they can be used as a way for citizens to discuss the challenges and complexities of taking action against shared issues. In the case of the Community

Champions, they thought about the causes of noise and how they are contributors to the problem in their daily actions. It also led to them discussing their affiliations to noise. Good noises and bad noises are subjective, but only through making data meaningful with indicators can this context be further understood as the sensor will only collect decibel readings.

For the residents of Gracia Sounds, introducing CLIs at the start was a pivotal point in their understanding of the problem. Having been burdened by noise pollution for a long period of time, residents joined the project feeling hopeless and frustrated. However, the opportunity to discuss and unpack the issue allowed them to devise new ways of perceiving the issue at hand. Brought in at the forefront of the project, CLIs provided a platform for the residents to understand the causes of the noise in their community and how those could be monitored with the sensor readings. It allowed them to develop a collective understanding of what noise pollution is and to see the many reasons for its existence. It also helped them to understand the different ways that the Smart Citizen Kit could support their process of inquiry, as they discussed and collectively decided on strategies and the indicators to complement the deployment of sensors.

### Tools and Techniques

To support the collection of CLIs in participatory sensing, having a set of methods and tools to draw on can support the accessibility and feasibility in this way of working. The bespoke Making Sense CLI tool was developed and iterated upon, with the final version employed in the wild [Figure 6]. Key factors that informed its development were simplifying the concept and facilitating discussions and collective decision making for the participants of the pilots. Furthermore, other methods, such the Noise Timeline and creating collective goals revealed the complex issue of noise. The sensing journals allowed for the citizens to annotate the sensor data, through monitoring activities that occurred during the sensing period.

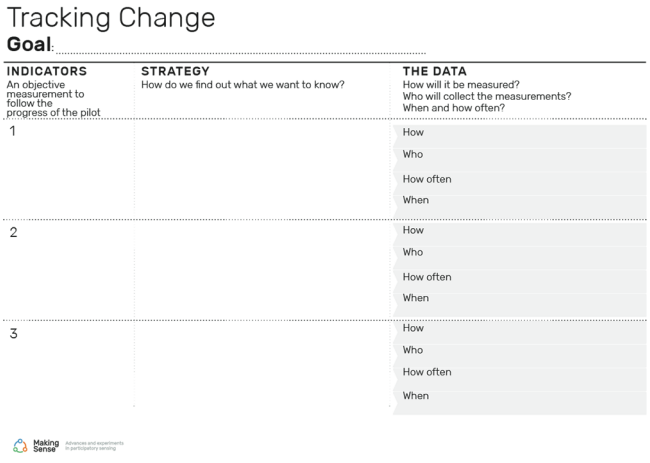


**Figure 6. The CLI tool with columns showing 1) Indicators 2) Strategy 3) The Data – How, Who, How Often and When**

### Accessibility

Ensuring the concept of CLIs is understood by citizens may enhance uptake of this approach. During the two pilots, the concept and tools used for CLIs were iterated upon. This was done primarily to enable the accessibility of the tool and concept. However, insights from the studies demonstrate that more can be done in this area. For instance, the participants of the Gracia Sounds pilot struggled to see a connection between the information they gathered and the strategies they devised during the CLIs activity. Demonstrating relevance and value of this way of working through success stories, e.g. Gracia Sounds, could make CLI's more tangible to future participants.

### Integration

One of the challenges for using the CLIs with the participants is that after the initial introduction to the concept, the right processes were not in place to help the participants to capture the information. We suggest having activities that coincide with the more passive action of deploying the sensor and collecting data would allow them to make sense of the data in the context of their lives.

Linking up experts to citizen activity could help in some of the more difficult monitoring, and would assist in developing the skills and knowledge of citizens. For instance, in both pilots there was an expression of interest in finding out how noise levels impacted health. The Gracia Sounds community is conducting continuing work with the local health agency to collect information on the health and wellbeing impacts of noise.

## IMPLICATIONS FOR FURTHER RESEARCH

We have examined an evolving approach of CLIs and considered how it can be one approach for the co-creation, interpretation and use of meaningful data within the domain of participatory sensing. In addition to framing the creation of data from the outset in terms of issues that matter to the individual, context and relevance. All of which has relevance in the development of the field of HCI.

The ongoing exploration of that data is likewise supported by CLIs. This provides an aid to interpretation, and makes the finding of meaning far more accessible to the non-expert. This, in turn, enables use of that data for creating action for environmental change.

However, more can be done in regards developing this approach and to supporting citizens with methods and tools for collecting CLIs. Once CLIs have been agreed on, there needs to be additional focus on monitoring the set of indicators. Without orchestration and guidance, this can become a hurdle. Citizens in the main have limited time in their daily lives to dedicate to meticulous data and information collection. There is a need to rely on the assistance of others, such as community champions, or accessible technology and other supportive devices. For future work, we suggest CLIs be integrated into grassroots initiatives on environmental issues, ensuring that the

participatory sensing work is built in concert with meaningful data.


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